Review article
Genetics of Canine Behavior

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Abstract

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Canine behavioral genetics is a rapidly moving area of research. In this review, breed differences in behavior are emphasized. Dog professionals' opinions of the various breeds on many behavior traits reveal factors such as reactivity, aggression, ease of training and immaturity. Heritability of various behaviors – hunting ability, playfulness, and aggression to people and other dogs – has been calculated. The neurotransmitters believed to be involved in aggression are discussed. The gene for aggression remains elusive, but identification of single nucleotide polymorphisms associated with breed-specific behavior traits are leading us in the right direction. The unique syndrome of aggression found in English Springer Spaniels may be a model for detecting the gene involved.

Dog aggression, heritability, temperament

Behavior is a result of nature (genetics) and nurture (learning or experience). We shall review the history of canine behavioral genetics and explore the latest findings. The publication of the canine genome allows us to make some inferences (Kirkness et al. 2003).

Foxes

One of the most thorough studies of canid behavioral genetics deals with foxes, not dogs. Selection for a tame and for an aggressive strain of silver foxes over 30 years by Dmitry Belyaev and Lyudmila Trut resulted in large differences in behavior and in morphology (Trut et al. 2006). The tame foxes were more likely to have spots, floppy ears, and curly tails. Tame and aggressive foxes have been bred and there are 300 backcross offspring (Trut et al. 2006). These three generation pedigrees are allowing Anna Kukekova and her colleagues at Cornell University to use linkage analysis to find the gene for tameness and for aggression. The karyotypic differences between fox and dog represent 26 chromosomal fusion and four fission events, so that anything learned about foxes will apply to dogs as well (Kukekova et al. 2006).

Breed Differences in Behavior

There are several approaches to classifying behaviors. We shall review four of these: breed differences in behavioral neoteny; breed differences in social signaling; breed differences in prevalence of behavior problems; and opinions of dog experts on behavioral characteristics of various breeds.

There are obvious physical differences among dog breeds and, although behavior does not vary as widely as size and skeletal features, there are marked breed differences in behavior. In fact, many lectures on canine genetics begin with a statement about genetic differences in behavior, but few of the genes are known. Dr. Yukari Takeuchi and her colleagues at Tokyo University have made the most progress and we will review their findings here.

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What are the different genotypes of dogs? Genetically, dogs can be placed in four clusters. The most genetically distinct are the Asian breeds: Chow, Akita, and sled dogs, such as the Husky. The second cluster includes the guard dogs, mastiffs, bull dog, boxer and Bernese mountain dog. The third cluster consists of herding breeds, the collie, and Shetland sheepdog, and some of the sight hounds, including the greyhound. The remaining cluster includes modern hunting breeds including gun dogs, hounds, and terriers (Parker and Ostrander. 2005). It is surprising that the Western breeds sort out genetically close to the American Kennel Club classifications. For example, the mastiff, bull dogs, pitbulls, and boxers, etc. are closely related to one another. The aggression noted in these breeds can certainly be explained as genetic. Rottweilers do not belong to that group despite their brachycephalic features. The hounds are closely related, as are the terriers.

Jackson Laboratory

Beagle, Basenji, Cocker Spaniel, Wire Haired Fox Terrier, and Shetland Sheepdog. The earliest and still most complete study of breed differences in canine behavior was performed by Scott and Fuller (1974) at Jackson Laboratory in Maine. This group, who also discovered the critical periods of socialization in dogs (Freedman et al. 1961), studied five breeds: cocker spaniels, wire haired fox terriers, basenjis, Shetland sheepdogs, and beagles. The five breeds were tested for their ability to learn three types of tasks: forced training, reward training, and problem solving.

The forced method of training was used to teach the dogs to sit still on a scale, to heel on a leash, and to stay and jump on command. In all three types of tasks, the cocker spaniels ranked highest in correct performance. The trainability of cockers in these situations is probably the result of selection within the breed for dogs that would crouch in response to a hand signal. Although cockers are not often used for hunting now, the behavioral predisposition remains. All the dogs learned to heel within the 10-day training period, but there were marked differences in the types of errors that dogs of the various breeds made in the early sessions. Basenjis fought the leash and often pulled ahead or lagged behind; Shetland sheepdogs interfered with the trainer, that is, tangled the leash around his legs. Beagles vocalized in protest. The breed differences in performance were evident on the first training trials and persisted, even though all the dogs improved.

Reward training consisted of showing the dog a piece of fish in a box and then restraining the puppy behind a wire gate before allowing him to run to the box and eat the fish. The position of the box was changed to measure goal orientation versus habit formation. Basenjis performed best on this test, probably because they could run the fastest. With the additional trials, all the dogs reduced the time they took to reach the reward. When motor skills of the five breeds were compared, the basenji was also best.

Problem solving was also studied. The first type of problem the dogs were supposed to solve was a barrier or detour. The dogs were separated from a food reward by a wire barrier. When they learned to run around a short barrier, the barrier was extended and later formed into a U-shape to increase the difficulty of the problem. The dogs were only 6 weeks of age and had considerable difficulty in solving the barrier problem that an adult dog could master easily. The puppies often yelped, and it was noted that they never solved the problem while yelping, but instead engaged in stereotypic activity. Few puppies did well on the barrier test, but basenjis, which are already active at 6 weeks, did best. Puppies of other breeds still tend to be fat and clumsy at 6 weeks and would react to failure by going to sleep.

Another type of problem was a manipulation test in which the dogs were tested for their ability to pull a dish of food from under a box by pawing or pulling it out with their noses. Later, the dish was positioned in such a way that it could be maneuvered out from under the box only by pulling on a dowel and string attached to the dish. Again, the basenjis were the most successful. When maze learning was tested in RLLRRR (right, left, left, and so on) or LRLL mazes, beagles did best. They completed the maze most quickly and made the fewest errors.

A final test of problem-solving behavior, when the dogs were 22 weeks old, was a delayed response test in which the dogs were shown a visual cue that indicated which side of a T-maze led to freedom. Before the dog was allowed to run the maze, a delay from 1 to 240 seconds was imposed. As in all problem solving, there were great individual differences, but cocker spaniels could remember after the longest delay, and Shetland sheepdogs had the poorest memory.

The extensive studies at Jackson Laboratory indicate that care must be taken in comparing intelligence, even within a species, since breeds of dogs differ markedly in their relative performance depending on the task to be learned.

The most intriguing result was the interaction of genotype and experience (Freedman 1958). Puppies were raised in isolation and exposed to either tolerant humans or disciplinary humans who made the puppies sit and wouldn't play with them. Later the puppies were presented one by one with a bowl of food. If they approached, the handler would clap his hands to frighten them away. The handler then left the room so the puppies were free to eat the food. The basenjiis did, no matter how they had been handled. The Shetland sheepdog never did, no matter how they had been handled. The disciplined beagles ate the food, but not the tolerantly treated ones. The conclusion is that identical handling will have different effects on different genotypes of dogs.

Border Collies and Newfoundlands

At the University of California at Berkeley, Jasper Rine and Elaine Ostrander crossed border collies and Newfoundlands. The F1 generation were bred to one another and in the F3 generation, the various behavior traits associated with each breed-retrieving and giving eye (staring at sheep or person) for border collies, and love of water and friendliness of Newfoundlands were inherited separately, so that some dogs loved water like Newfoundlands and gave eye like border collies (McCaig 1996).

Nervous Pointers

At the University of Arkansas, selective breeding for five generations resulted in two strains of pointers - a nervous (E) and a normal strain (A). The former are much more difficult to train (Murphree et al. 1974) and the tricyclic anti-depressant imipramine does not improve their behavior (Tancer et al. 1990). The results indicate that nervousness or aversion is a result of additive gene action. The A dogs are friendly, active, people-seeking dogs, whereas the E are nervous, exhibit marked timidity, reduced activity, little exploratory behavior and nearly catatonic immobility when people are nearby. Their heart rate is markedly reduced and their eyes are directionally fixed.

Deafness can be diagnosed behaviorally by observing a dog's response to a sudden noise. This is easiest to do when the dog is panting in a warm environment. He will interrupt his panting if he hears the sound. A more quantitative method is the brainstem auditory evoked response (BAER). A speaker is placed in the dog's ear and sound played through it. Recordings are made from electrodes placed on the neck over the hindbrain. In a normally hearing dog, a change in voltage will occur in every synapse from the auditory nucleus to the cortex - eight in all. If the dog is deaf, there will be no change in voltage. Sounds may be played at various decibels, to detect partial deafness and at various frequencies. Using BAER technology, Steinberg et al. (1994) have detected an autosomal recessive deafness in some of the nervous pointers. The relationship of the auditory problem to the nervous behavior is unknown, but appears insufficient to explain the behavior (Klein et al. 1988).

Expert Opinion of Breed Behavior Differences

The largest study of opinions of breed differences is that of Hart and Miller (1985). They surveyed 48 veterinarians and 48 obedience judges as to 13 traits in 56 breeds of dog. The thirteen characteristics were: excitability; general activity; snapping at children; excessive barking; demand for affection; territorial defense; watchdog barking; aggression toward other dogs; dominance over the owner; aptitude for obedience training; ease of house breaking; destructiveness; and playfulness. The breeds were ranked by decile. Dogs in the tenth decile rank higher than 90% of other breeds for that characteristic. Those in the first decile rank below all the other breeds in that characteristic. Let us compare three breeds: the beagle, golden retriever and German shepherd. The beagle ranks in the eighth decile for excitability, the ninth for general activity, the fifth for snapping at children, the ninth for excessive barking, and the third for demand for affection, the third for territorial defense, the fourth for watchdog barking, the fifth for aggression toward other dogs, the eighth for dominance over the owner, the first for obedience training and ease of house breaking, the seventh for destructiveness, and the fifth for playfulness. The beagle is hard to obedience train and housebreak, barks a lot, and is inclined to be dominant over the owner.

The German shepherd ranks in the fifth decile for excitability, the fourth for general activity, the fifth for snapping at children, the sixth for excessive barking, the third for demand for affection, the ninth for territorial defense and watchdog barking, the eighth for aggression toward other dogs, the seventh for dominance over the owner, the ninth for obedience training, and the eighth for ease of house breaking, the ninth for destructiveness, and the seventh for playfulness. German shepherds are good watch dogs and easy to train, but destructive and inclined to be dominant over the owner.

The golden retriever ranks in the second decile for excitability, the fourth for general activity, the first for snapping at children and for excessive barking, and the seventh for demand for affection, the first for territorial defense, the third for watchdog barking, the first for aggression toward other dogs and dominance over the owner, the ninth for obedience training, and the sixth for ease of house breaking, the first for destructiveness, and the eighth for playfulness. Golden retrievers are trainable and playful, but not aggressive.

Principle components analysis revealed 3 factors – reactivity, aggressiveness, trainability – and a fourth factor that included playfulness and destructiveness. Cluster analysis of breeds with similar traits revealed seven clusters. It is interesting that snapping at children clusters with reactivity, not with aggression. They also found that those surveyed believed that there were large differences between intact males and females in behavioral traits. Females were more trainable and males were more aggressive.

Bradshaw et al. (1996) performed a similar study in which veterinarians and dog-care professionals rated various breeds of dogs on a 13 point scale. Factor analysis revealed three traits: aggressivity, reactivity, and immaturity. This resulted in eight groups which did not correspond to the breed groupings. Examples are high aggressivity, average reactivity, low immaturity (Rottweiler); high aggressivity, average reactivity, high immaturity (Jack Russell); average aggressivity, low reactivity, low immaturity (British bulldog); average aggressivity, high reactivity and low immaturity (toy poodle); low aggressivity, average reactivity, high immaturity (English setter); low aggressivity, low reactivity, low immaturity (Greyhound); low aggressivity, high reactivity, low immaturity (King Charles spaniel); average aggressivity, average reactivity, average immaturity (Samoyed).

Dog breeds are typically divided according to historical usage into Working, Hunting, Herding, Hound and Terrier groups plus the toy group, and, in some countries, a separate Gun dog group. When the results of a temperament test involving reactions to strangers who attempt to play tug of war with the dog are compared to the historical use of the dog (for guarding, hunting, etc.), there is little correlation, but there is a similarity in response within a breed. Most interesting is that two of the most popular breeds, the Labrador and the golden retriever, the latter is fearful, the Labrador bold. These results suggest that the present use of a dog differs from the historical use (Svartberg 2005).

Breed Differences in Neoteny

Coppinger and Schneider (1995) compared breeds on both behavioral and physical characteristics which they believe co-evolved. Some have puppy-like facial features - short nose and full cheeks, whereas German shepherds are fully adult with long noses and narrow cheeks. They ranked the breeds by developmental stages: heelers (huskies and corgis), headers-stalkers (collies), object players (hounds, retrievers, and poodles), and adolescents (St. Bernard, komodors, and great Pyrenees). These sheep guarding dogs show juvenile behavior, such as play, and lack mature sexual behavior.

Breed Differences in Communication

Goodwin et al. (1997) examined breed differences in signaling. They observed wolves and listed the signals they observed such as growl, stand over and stare, crouch, and submissive grin. Ten breeds of dogs were compared to wolves. These dogs lived in same breed groups, ranging in size from four to seven. They were observed for several hours and the behaviors they exhibited compared to those of wolves. Siberian huskies were most like wolves; Labrador retrievers were the next most wolf-like. At the bottom were cavalier King Charles spaniels, Norfolk terriers, and French bull dogs. The authors interpreted this as meaning that behaviors had been lost with domestication due to paedomorphosis.

Breed Differences in Behavior Problems

The statistics on deaths caused by dogs allows one to determine breed differences in aggression. Between 1979 and 1998, pitbulls killed the greatest number of people followed by Rottweilers, German shepherds, huskies, malamutes, Dobermans, and chows (Sacks et al. 2000). These are all large breed dogs, but other popular large breeds such as Labradors and golden retrievers are not on the list. It is most interesting that Rottweilers have overtaken pitbulls and now kill more people per year. The number of Rottweilers registered had increased 5-fold between 1979 and 1998, but the number of fatalities increased seven times. The statement is often made that popularity ruins the breed, but what probably happens is that while the percentage of aggressive dogs within a breed remains the same, the total numbers increase so there are more aggressive dogs of that particular breed. Unfortunately, these statistics and the tendency of people to sue if bitten have led homeowner insurance companies to refuse policies to people who own pitbulls or Staffordshire terriers, Rottweilers, chows, and dobermans. Breed-specific legislation has been enacted in only a few communities, but the insurance companies are essentially doing that throughout the USA.

We have been interested in aggression by dogs toward their owners. Although many breeds (Doberman pinschers, Rottweilers, German shepherds) have been selected for aggression to humans, toward vermin (terriers) or toward game, (the Japanese bear dogs, otter hounds) etc., none have been selected to bite the hand that feeds them. There is a breed that has developed this trait - the English springer spaniel (ESS). This is a serious problem and led us to try to search for the gene for aggression. There was a similar aggressive problem in Bernese Mountain dogs, but the breeders were able to select against it and essentially eliminate the problem (Van Der Velden et al. 1976).

There are breed differences in the behaviors for which dogs are referred to clinical animal behaviorists (Mugford 1984; Podberscek and Serpell 1996; Podberscek and Serpell 1997a&b). Borchelt (1983) classified the types of aggression he treated in his urban consultations. Dominance aggression was most common in English springer spaniels, doberman pinschers, toy poodles, and Lhasa apsos. Possessive aggression was most common in cocker spaniels. Protective aggression was most common in German shepherds, but fear aggression was also common in that breed, as well as in cocker spaniels and miniature poodles.

Of course, breed differences in prevalence have to be compared with the numbers of dogs of each breed in the catchment area. When comparing a private practice in Ontario, a private practice in Kansas, and a university clinic in upstate New York, Landsberg (1991) found that English springer spaniels were most often presented to the eastern clinics but not to the midwestern one. Two other behavior problems - separation anxiety and thunder phobia - revealed no breed differences. Historically, ESS present with dominance-related aggression more than would be predicted by regional breed distributions (Beaver 1993) and by national breed registration statistics (Landsberg 1991).

The reaction of the dog to threats to its personal space or to attempts to take a coveted object from him are more likely to reveal owner-directed aggression. A behavior screen originally developed by Victoria Voith (Voith 1996) is an invaluable tool in understanding the dog's personality. For example, the dog's response to food in his proximity, both his usual ration and human food, may be no response, a growl, a snap, or a bite. The owner checks the appropriate box - and most owners are honest because they want the dog to be better. The dog's reaction to being approached when on the bed or couch, to having its leash or collar touched, or to any reprimand is also telling. A classical form of aggression is toward one member of the family, usually the male, when he approaches the dog and wife who are on the bed or couch. This may be mate guarding or a form of possessive aggression in which the woman is the possession. Questions are also asked about the dog's reaction while on and off leash to strange humans and dogs.

The responses of aggressive ESS on the aggression screen used at Cornell University Animal Behavior Clinic were distinct from the responses of aggressive dogs of other breeds. When frequency scores for ESS and non-ESS aggressive dogs were compared across the aggression screen, the responses for ESS and non-ESS diverged on a subset of questions related to dominance, feeding, and territoriality. When analyzed by subscales, aggressive ESS were not different from other aggressive dogs except on three subscales. Aggressive ESS were not different from control ESS in severity on the child-directed and territorial aggression subscales, although aggressive non-ESS scored significantly higher than controls on both. Conversely, aggressive ESS were more severe on the food related aggression subscale, while aggressive non-ESS were not different from controls.

The comparison of aggressive ESS and other breeds of aggressive dogs found a clear distinction in responses to dominance and food-related situations (ESS more frequent than non-ESS) and to territorial situations (non-ESS more frequent than ESS) (Golden et al., personal communication).

Reisner et al. (2005) reported in a survey of over 2000 ESS that 65% of ESS with a history of biting (27% of total ESS) had bitten a familiar person, indicating that dominance-related aggression is more frequent than territoriality-related aggression among ESS. The fact that dominance-related aggression and territorial aggression can be dissociated between ESS and non-ESS, as the Golden and Reisner studies reveal, suggests that they are two distinct types of aggression.

There is a syndrome in English cocker spaniels very similar to that seen in English springer spaniels (Mugford 1984; Podberscek and Serpell 1996; 1997a; 1997b). The dogs are most likely to bite their owners. Most affected dogs are male. In this case, there is a coat color association - red cockers are most likely to bite followed by black, and then parti-colored.

Heritability

There have been several studies of heritability of traits in dogs. Heritability is the proportion of variation of a trait that can be explained by genetics.

Hunting Dogs

The traits important for hunting have been examined - pointing, nose use, search and retrieval.

Heritability of a hunting behavior was investigated by the Swedish Flatcoated Retriever club, as well as to investigate the existence of broader personality traits. During the test, the dog was exposed to various standardized hunting situations and the intensity of its reactions was scored in a test protocol by approved test leaders. The data consisted of observations for 10 traits on approximately 800-1150 dogs (depending on trait) and for two additional traits recently added to the test (with only about 190 observations). The dogs were tested in the period from 1992 to 2000. Almost all traits were affected by the test leader, the test object (dummy or game) and previous experience, whereas age and sex affected fewer of the reactions. Heritability estimates for the 10 traits were generally between 0.1 and 0.4, with an outlier of 0.74, and several of the traits were highly genetically correlated. A factor analysis on estimated breeding values revealed three factors which were interpreted as broader personality traits named: excitement, willingness to retrieve, and independence. These personality traits had heritabilities of 0.49, 0.28, and 0.16, respectively, and were weakly genetically correlated with each other (from -0.08 to 0.15) (Lindberg et al. 2004).

Heritability of hunting performance of gun dogs in Norway was tested. Dogs were tested individually and performances of seven traits were judged by scores from 1 to 6. The traits are: hunting eagerness, speed, style, independence, seeking width, ability to work in the field, and cooperation. In addition, the number of birds found in the test was recorded. Genetic parameters for three breeds, German short-haired pointer, German wire-haired pointer, and Brittany spaniel were estimated. The estimated heritabilities for the scored hunting performance traits varied from $h^2 = 0.06$ to 0.28. The genetic correlations between some of the performance traits were estimated to be higher than the phenotypic correlations and were close to 1.0 (Brenre et al. 2002).

Results of field trials revealed that Finnish Hounds were found to have the highest heritability scores for pursuit and tongueing (vocalization while in pursuit of a hare or fox) (Liinamo et al. 1997).

Working Dogs

Ruefenacht et al. (2002) calculated the heritability of temperament of Swiss army dogs to be low based on seven traits. The traits were: 1) affability (tested by having an unknown person approach the dog); 2) disposition for self defense (an unknown person attacks the dog); 3) disposition for self defense and defense of the handler (tested by having an unknown person attack the dog and the handler); 4) disposition for fighting in a playful manner (tested by asking the dog to fight for a sleeve or a stick); 5) courage (tested by having a man-shaped figure approach the dog); 6) ability to meet with sudden, strong auditory stimuli (tested by firing a gun at a distance and by making noise with tin cans just behind the dog); 7) disposition for forgetting unpleasant episodes (tested by scaring the dog at a certain location and then asking the dog to pass the location again); and adaptiveness to different environments and situations (tested by observations throughout the test). The estimate of heritability of these traits was low.

Of most interest to us is heritability of aggression. MacKenzie et al. (1985) examined the scores of German shepherd dogs used for attack work during World War II. The heritability of temperament was determined using 575 German shepherd dogs from the Division of Biosensor Research of the US Army. The specifics of the temperament test were not mentioned, but were all determined by one person and composite scores were used to predict future performance and indicated the animal's ability to chase and attack a decoy, and to use its sense of smell. The hip dysplasia scores also were assigned by one person. There was a negative correlation between temperament and hip dysplasia scores. MacKenzie et al (1985) found from the scores of the dogs on their temperament tests and their pedigrees that aggressiveness - that is suitability - in an attack or sentry dog was heritable at 0.51. He also found that the best scores were associated with the worse hip scores. More recent work did not find this pattern, so the genes for the two conditions must not be closely linked (Ruefenacht et al. 2002).

Heritability of various behaviors of German shepherd puppies bred to be working dogs in Sweden by Wilsson and Sundgren (1998) was tested. The test was divided into two parts: fetch and retrieve, and vocalization. Willingness to retrieve objects in general was considered a good measurement of cooperativeness. Willingness to play tug of war and to approach a stranger were also evaluated.

The scores of 630 German shepherd puppies tested at eight weeks of age were used to calculate heritability. The heritability of the puppy's response was highest for activity (0.53), tug of war (0.48), and contact (0.42). Other estimates of heritability range from 0.20 to 0.27. Higher estimates on dam than on sire were found for shriek, contact, tug of war, activity, and objects visited. This indicates the environmental effect.

Pet Dogs

Aggression to Owner

Of course, what is good temperament for an attack dog is not necessarily good temperament for a pet dog. In fact, most of the commonly used temperament tests rely on the dog's reaction to strange people and dogs and do not measure the reaction of the dogs to challenges by the owner (Jones and Gosling 2005). Another problem is that dogs may take a test, such as the Canine Good Citizenship test, when the dog is a year old, but the dog can become aggressive as most at genetic risk do, at two years of age.

Dominance

The Campbell Test was conducted to assess dominant behavior in puppies. The test consisted of five parts and must be conducted at the age of six to eight weeks old. Puppies were subjected to the test individually with no other person, animal or object present that could distract them. The tester, who had not seen the puppy previously, remained impassive and showed no signs of emotion throughout the test. The five parts of the test included: social attraction, following, restraint, social dominance (petting), and elevation dominance (picking up).

The Campbell test applied to 51 seven week old English cocker spaniel puppies, the offspring of four sires and 10 dams, revealed a hierarchy of dominance of 0.20 based on sire and heritability estimated on the dam of 0.46, indicating both genetic and environmental influences. It is particularly interesting that seven week old puppies demonstrate the same differences due to coat color and sex as adult English cocker spaniels, that is solid color and male puppies are more dominant than particolor and female puppies (Pérez-Guisado et al. 2006).

There is high heritability of aggression – at least in adult Golden retrievers, with heritability estimates of scores of 0.9 for aggression toward strangers (van den Berg et al. 2006).

Liinamo et al. (2007) used Restricted Maximum Likelihood method to determine heritability of aggression using the dog owner's impression of the animal's human and dog-directed aggression or the responses on the Canine Behavioral Assessment and Research Questionnaire (CBARQ) (Hsu and Serpell 2003). They found heritability of 0.77 for human-directed aggression and 0.81 for dog-directed aggression. There is little correlation between the two types of aggression indicating separate genetic causes of the traits. There were high heritability estimates on several CBARQ items such as strange dog approaching leashed dog (0.85), family member grooming dog (0.83), family member approaching eating dog (0.94), family member removing food (0.95), stranger trying to touch dog (0.99).

These studies indicate that dominance behavior and aggression are under genetic control and have encouraged research in the genetics of canine aggression and other misbehaviors.

Genes and Behavior

The hunt for the gene involved in aggression is very difficult. For example, one may select one neurotransmitter - for example serotonin, and determine genetic difference between aggressive and non-aggressive dogs. The difference between aggressive and non-aggressive dogs could be due to a gene controlling synthesis of the neurotransmitter, reuptake of the neurotransmitter, the enzymes that inactivate the neurotransmitter, or genes that control expression of any of the above genes.

Neurotransmitters

Dopamine

Dopamine is a neurotransmitter frequently affected by veterinary drugs. For example, acepromazine is a blocker of dopamine receptors and is used for sedation. There is an association between novelty seeking in humans and the long form of the D4 dopamine receptor (Benjamin et al. 1996; Ebstein et al. 1996). Dopamine is inactivated by an enzyme, monoamine oxidase. Aggression can occur in humans with a particular mutation of the enzyme (Caspi et al. 2002).

Serotonin (5-hydroxytryptamine 5-HT)

Genes involved in serotonin's production and that of its receptors are promising candidates in the genetic control of aggression. Lesch et al. (1996) found an association between anxiety and polymorphism in the serotonin transporter gene. Saudou et al. (1994) found that mice lacking the 5-HT 1 β receptor for serotonin were more aggressive to strange mice, which is a behavior analogous to territorial aggression in dogs. Conversely, mice lacking the receptor for substance P, the neurotransmitter that modulates sensitivity to pain, were less aggressive to strange mice (De Felipe et al. 1998). There is considerable evidence in primates, rodents, and dogs that aggressive individuals have lower cerebrospinal levels of 5-hydroxyindole acetic acid and homovanillic acid, the major metabolites of serotonin and dopamine respectively (Reisner et al. 1996). Furthermore, drugs that block the reuptake of serotonin such as amitriptyline (Virga et al. 2001) and fluoxetine (Dodman et al. 1996) decrease aggression in dogs, as well as in other species.

Norepinephrine

Alpha 2 adrenergic receptors appear to modulate aggression because knockout mice lacking the alpha2c receptors were more aggressive to strangers (Sallinen et al. 1998).

Genes and Aggression

There are many studies in mice demonstrating that certain genes influence aggression, whether any of these are involved in canine aggression remains to be determined.

Targeted disruption of a single gene - a knock out - is a powerful tool with which to study behavior in laboratory mice. Knock out of the estrogen receptor reduces aggression in female mice (Scordalakes and Rissman 2003). Neuronal nitric oxide is involved in many reactions; knock out of the neuronal nitric oxide synthetase gene increases aggression (Nelson et al. 1995). Knock out of the gene for alpha calcium calmodulin kinase II in tailless mice (Nelson and Young 1998) also results in aggression.

A gene coding for steroid sulfatase is located on the Y chromosome and the levels of enzyme are correlated with aggression against intruder male mice (Le Roy et al. 1999). Mice with smaller infra pyramidal mossy fiber terminal fields due to a one gene mutation were more aggressive (Sluyter et al. 1999).

Genes and Canine Behavior

There have been several promising candidate genes for canine aggression. These include the dopamine D4 receptor, the long form of which is associated with risk seeking behavior in humans (Noble et al. 1998) and monoamoine oxidase A, an enzyme which breaks down dopamine and a mutation of which is associated with incarceration of humans, if they had a bad childhood environment (Caspi et al. 2002).

The results of the candidate gene approach to canine aggression have been uniformly disappointing so far. Although Nimi and colleagues (1999) showed that a usually gentle breed of dog, the golden retriever, had the short form of the dopamine D4 receptor and the territorially aggressive Shiba has the long form, this is not associated with behavior but rather with the genetic differences between an Asian and an Anglo-American breed (Parker et al. 2006).

Van den Berg et al. (2003; 2005; 2006) investigated 4 genes involved in serotonin function: serotonin receptor 1A, (htr1A); serotonin receptor 1B (htr1B); and serotonin receptor 2A (htr2A); serotonin transporter gene (slc6A4). Linkage analysis of pedigrees of Golden retrievers did not demonstrate that any of these genes were linked with aggression.

The laboratory of Veterinary Ethology of Tokyo University has made the most progress in locating putative genes affecting canine behavior. They have obtained blood samples from five breeds of dogs: golden retriever, Labrador retriever, Maltese, miniature schnauzer, and Shiba for a total of 266 samples. They have systematically searched for differences in single nucleotide polymorphisms in genes for neurotransmitters, the enzymes that synthesize them or destroy them, and the receptors. They have compared the differences in genotype with the differences in behavior in the breeds as found by Hart and Hart (1985) and Hart and Miller (1985). The details are given below.

Hashizume et al. (2003) determined the full-length nucleotide sequences of cDNA for canine monoamine oxidase type A (MAOA) and type B (MAOB) genes that were isolated from the canine brain cDNA library. Oligonucleotide primers for PCR were constructed based on the conserved sequences reported thus far for other mammalian species. The nucleotide sequences had open reading frames of 1584 and 1563 bp for MAOA and MAOB, respectively. Both of these genes showed relatively high homology with other species in both nucleotide (> 81%) and deduced amino acid (> 85%) sequences. In Northern blot analyses, MAOA mRNA was expressed broadly in various parts of the canine brain, whereas MAOB mRNA was found only in specific brain regions, such as the hypothalamus, hippocampus, brain stem and olfactory bulb. These results suggested that MAOA and MAOB mRNAs have subtype-specific expression patterns in the canine brain. Because mutations in monoamine oxidase have been associated with aggression in humans, (Caspi et al. 2002), these canine mutations should be examined in aggressive and non-aggressive dogs. Hashizume et al. (2005) found that 90% of Golden retrievers – a friendly breed – had the T allele of the MAOB gene, whereas the more aggressive and excitable Schnauzers had less than 90%.

Masuda et al. (2004a) identified the canine catecholamine o-methyl transferase (COMT) gene fragment and found its genetic distribution among five representative canine breeds: retriever, Labrador retriever, Maltese, miniature schnauzer, and Shiba. The amplified gene consisted of 663 bp nucleotides and was 84% homologous with the human COMT gene. Single nucleotide polymorphisms, guanine adenine substitution, were observed at the 39th (G39A), 216th (G216A) and 482nd (G482A) nucleotides. From the genotyping of the 216th polymorphism among 266 dogs by the polymerase chain reaction-restriction fragment length polymorphism method with restriction enzyme EagI, and that of the 482nd polymorphism with restriction enzyme SfcI, inter-breed variations of genotypes as well as of allelic frequencies were found for both of these polymorphic regions. The G/G genotypes was dominant in the five breeds tested – golden retriever, Maltese, miniature schnauzer, and Shiba, but Labrador retriever and miniature schnauzer had more A alleles. Territorial defense is higher in Labrador retrievers and miniature schnauzers than in Maltese and golden retrievers.

Masuda et al. (2004b) searched for polymorphisms of serotonin receptors in the dog and compared allelic frequencies for the canine 5-HTR1B, 5-HTR2A, and 5-HTR2C genes among five canine breeds. The canine genes consisted of the following: 5-HTR1B, 1170 bp; 5-HTR2A, 1413 bp; and 5-HTR2C, 1377 bp. All of these genes were highly homologous with the human genes. There were no polymorphisms in the 5-HTR2A, and 5-HTR2C genes. They found six single nucleotide polymorphisms (SNPs) in the 5-HTR1B gene (G57A, A157C, G246A, C660G, T955C, and G1146C). Genotyping of the respective SNPs revealed that there were inter-breed variations in the genotypes and allelic frequencies for four out of the six identified SNPs. The G57A and A157C polymorphisms were observed only in golden retrievers. The G246A and C660G polymorphisms were not observed in Maltese or miniature schnauzers in which the C allele of the G1146C and T955C polymorphisms was dominant, whereas other alleles were dominant in the other four breeds.

Ogata et al. (2006) identified a single nucleotide polymorphism (T199C) located on the putative third exon of the canine monoamine oxidase B gene, which causes an amino acid substitution from cysteine to arginine. They examined the allelic frequencies in five dog breeds (Golden retriever, Labrador retriever, Maltese, miniature schnauzer, and Shiba) and found significant variation among them.

Takeuchi et al. (2005) used brain cDNAs derived from ten unrelated Beagles to search for polymorphisms in tyrosine hydroxylase (TH) and dopamine beta hydroxylase (DBH), the enzymes synthesizing norepinephrine and dopamine, respectively. Four single nucleotide polymorphisms (SNPs) (C97T, G168A, G180A and C264T), one of which (C97T) will cause amino acid substitution in the TH gene, and two SNPs (C789A and A1819G), both of which will cause amino acid substitutions in the DBH gene were identified. The allelic frequencies among five dog breeds (47 golden retrievers, 41 Labrador retrievers, 40 Malteses, 26 miniature schnauzers, and 39 Shibas) were examined and found to have significant variation between them with regards to all these SNPs, except for C97T in the TH gene and A1819G in the DBH gene which were found only in the Shiba. The alleles of 168A and 264T on the TH gene are found in relatively high frequency in the Labrador retrievers which are higher in ease of housebreaking and low on attention demand and general activity than the other breeds. At G180A, the Labrador retriever and miniature schnauzer, which rank higher in territorial defense, have more A alleles than the other breeds. At C789A, the ratio of allelic frequency of the golden and Labrador retrievers to other breeds is reversed. Retrievers rank lower in dominance over the owner, watch dog barking, snapping at children, destructiveness, aggression to other dogs, and excessive barking in comparison to other breeds.

Ogata et al. (2006) screened four excitatory amino acid transporters (EAAT) genes (glutamate transporter-1; GLT-1, excitatory amino acid transporter 4; EAAT4, excitatory amino acid carrier; EAAC1, glutamate/aspartate transporter; GLAST) for single nucleotide polymorphisms (SNPs). They identified two silent SNPs (C129T and T471C) in the GLT-1 gene. Next, they genotyped 193 dogs of 5 breeds and found significant variation among breeds in these two SNPs in GLT-1. The C129T polymorphism was not observed in Malteses and miniature schnauzers. The T allele variant of the C129T polymorphism was observed only in golden retrievers, Labradors and Shibas, breeds that have low excitability (Hart and Hart 1985). Golden retrievers and Labradors had a relatively higher proportion of the C allele of the T471C polymorphism, the miniature schnauzers and Shiba had a higher proportion of the C and T allele; the C and T alleles were approximately equal in Maltese.

Labrador retrievers and golden retrievers differ behaviorally from Shiba and schnauzers on defensive aggression.

Conclusion

Although we have not yet identified the gene or genes responsible for canine aggression, that should occur within the next year. At that point, the ethical problem arises of what to do with dogs that carry the aggressive genes. Certainly none of those dogs should reproduce, so should be neutered, no matter how beautiful they are. Should these dogs be euthanized before they seriously injure a person at worst or, at best, frighten and worry their owners who will not be able to enjoy the dog as a pet? That is a question all of us interested in public safety, the human animal bond, and in veterinary animal behavior should ponder.

Genetika chování psů

Psí behaviorální genetika je rychle se rozvíjející oblast výzkumu. V tomto přehledu jsou zdůrazněny rozdíly v chování u různých plemen. Názory odborníků na různá plemena a znaky chování odhalují faktory jako například reaktivitu, agresi, schopnost učení a nedostatečnou vyspělost. Byla sledována heritabilita různých vloh, schopnost lovu, hravost, agresivita vůči lidem a jiným psům. Jsou diskutovány neurotransmitery, o kterých se předpokládá, že se uplatňují při agresi. Gen pro agresi zůstává nepoznán, ale identifikace jednotlivých nukleotidových polymorfismů spojených s povahovými rysy charakteristickými pro jednotlivá plemena nás vede správným směrem. Unikátní syndrom agrese zjištěný u anglického špringer španěla, by mohl být modelem pro detekování příslušného genu.

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